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Smith, T.W.; Smith, R.E.; and Cortright, D.J.


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The Portable Borehole Deflectometer, a device for measuring the deflections along a prepared borehole, was evaluated under field conditions. It was concluded that the use of the instrument is limited to the monitoring of locations where the movement within the soil mass is along a well defined failure plane. The equipment is well constructed, but is awkward to use because of the length of probe and combined weight of rod and probe.



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# HIGHWAY RESEARCH REPORT

# EVALUATION OF THE PORTABLE BOREHOLE DEFLECTOMETER

## INTERIM REPORT

68-29

**STATE OF CALIFORNIA**

**TRANSPORTATION AGENCY**

**DEPARTMENT OF PUBLIC WORKS**

**DIVISION OF HIGHWAYS**

**MATERIALS AND RESEARCH DEPARTMENT**

**RESEARCH REPORT**

**NO. M & R 632722-1**

Prepared in Cooperation with the U.S. Department of Transportation, Bureau of Public Roads April, 1968

STATE OF CALIFORNIA—TRANSPORTATION AGENCY RONALD REAGAN, Governor

DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
5900 FOLSOM BLVD., SACRAMENTO 95819

April 18, 1968

Interim Report
M&R No. 632722-1

Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is a research report titled:

EVALUATION

OF THE

PORTABLE BOREHOLE DEFLECTOMETER

A sub-project of:

REBOUND OF MATERIALS IN HIGHWAY CUTS

TRAVIS SMITH
Principal Investigator

ROBERT E. SMITH and DONALD J. CORTRIGHT
Co-Investigators

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

REFERENCE: Smith, T. W., Smith, R. E., Cortright, D.J., "Evaluation of the Portable Borehole Deflectometer," State of California, Department of Public Works, Division of Highways, Materials and Research Department, Research Report 632722-1, April, 1968.

ABSTRACT: The Portable Borehole Deflectometer, a device for measuring the deflections along a prepared borehole, was evaluated under field conditions. It was concluded that the use of the instrument is limited to the monitoring of locations where the movement within the soil mass is along a well defined failure plane. The equipment is well constructed, but is awkward to use because of the length of probe and combined weight of rod and probe.

KEY WORDS: Boreholes, deflections, measurements, field investigations, field measurements, earth movements, measuring instruments, subsurface explorations, evaluation.

## ACKNOWLEDGMENT

Acknowledgment is extended to the following persons for their assistance in this project: Earl Bagley, Frank Hammill, and Bill Fuller of the Calaveras Cement Company; Horst Ublacker of Terrametrics, Inc.; and Joseph J. Spaeth, Calaveras County Road Commissioner.

The work reported herein was authorized as a portion of the research project, "Rebound of Materials in Highway Cuts." This work was done under the 1965-66 Work Program HPR-1(4), D-5-10, in cooperation with the U.S. Department of Transportation, Federal Highway Administration, U.S. Bureau of Public Roads.

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## INTRODUCTION

There is a reoccurring, if infrequent, need for means of measuring small internal movements in rock and earth masses. This need usually occurs at sites of potential or known instability. For example, surface movement of a known slide may be observed. If the sliding surface can be located, the possible consequences of the movement can be evaluated, and corrective measures determined.

The portable borehole deflectometer is an instrument designed to measure the deflections along a prepared borehole by the relative deflection of two arms of a jointed probe. It is available through Terrametrics Inc., of Golden, Colorado. It was thought that this device might be a potential tool for the study of movement occurring as a result of highway excavations; as well as a means of investigating landslides.

To enable a preliminary evaluation of the deflectometer, an active slide on a Calaveras County road adjacent to the Calaveras Cement Co. limestone quarry was investigated.

## CONCLUSIONS

The borehole deflectometer is considered suitable for determining movements along well defined planes within a soil mass. It is less capable in determining a gradual distributed movement along a borehole. This is because the deflectometer only detects differential deflections within the length of the measuring probe and does not accumulate deflection over the length of the hole. The instrument is entirely dependent on the relative movements of the portions of the jointed probe, and does not have a means of external reference such as a gravity pendulum. It is, therefore, insensitive to general rotational movements of the soil mass in which the borehole is located, which a pendulum type subsurface device could detect. Neither type instrument, of course, can discern plane translatory movements of the entire soil mass.

The deflectometer is well constructed, and seems to be satisfactorily stable over a period of time. However, facilities should be locally available to calibrate the unit against known deflections. The instrument is somewhat awkward and cumbersome to use in the form supplied for this program.

It is concluded that the borehole deflectometer is suitable for a limited type of work, such as monitoring movement occurring at a well defined failure surface. It is not satisfactory for rebound research. No further work is planned at this time by the department for the deflectometer.

## DISCUSSION

### REBOUND PROJECT

A project titled, "Rebound in Materials in Highway Cuts," was initiated in 1965 by the Materials and Research Department, and was approved as a federal research project in April of that year. The first phase of this research involved the measurement of rebound during excavation of a deep cut on Road 07-LA-5. This project is located about 40 miles north of Los Angeles. Also, field seismic studies were made and cored samples were tested. The object of this work was to measure the direction and magnitude of movement, evaluate its possible effect on stability, and compare the movement with predictions based on seismic and laboratory testing.

The report on the first phase is currently in preparation. Additional rebound research in connection with a deep excavation on 02-Sis-5 near Yreka is being considered.

The evaluation of the portable borehole deflectometer was proposed as a portion of the rebound project described above, and was authorized by the Bureau of Public Roads in September 1965.

### DEFLECTOMETER PROJECT

In June, 1965, a distressed road condition near the town of San Andreas in Calaveras County was brought to the attention of the Materials and Research Department. This roadway is locally identified as the "cement plant road," and is on a sidehill directly adjacent to the Calaveras Cement Company's open pit excavation for limestone. There is approximately a 110 ft. difference in elevation between the road and the bottom of the pit. The distress is in the form of widening cracks across the roadway. These define a crescent shaped wedge of earth that is apparently an active slide. The magnitude of movement has been sufficient to require periodic patching of the asphalt surfacing.

The Calaveras Cement Company had established two survey lines across the slide area. One of these lines was along the county road, and the other along a company haul road below and parallel to the county road. The horizontal and vertical alignment of points on these lines were measured at intervals by the company.

An investigation of this movement was made by the Materials and Research Department at the request of District 10 of the California Division of Highways, and Calaveras County. About this time information was received on the portable borehole deflectometer, and it was proposed to evaluate the instrument at the site of the distress as a cooperative project by the Materials and Research Department, District 10, Calaveras County, and the Calaveras Cement Company.

The immediate objective of the participation of this department was to determine if the deflectometer could be of use in the rebound research. It was also hoped that greater information concerning the nature of the particular slide could be gained. For the investigation, the Materials and Research Department leased the deflectometer and did the field work. The cement company drilled the boreholes on their service road just below the distress in the county road. They also supplied the cement and grouting equipment. District 10 and the Calaveras County Road Department provided the cooperation of their respective offices in the coordination of the project.

Upon approval of the research, a service contract between the Division of Highways and Terrametrics, Inc., of Golden, Colorado was executed. This contract provided for an initial evaluation period of 60 days at a fixed sum, and extensions or additional operation periods at fixed sums per month. Provisions were made for the purchase of certain minor items from Terrametrics, and for the services of a consultant. The initial evaluation period with the deflectometer was during December - February, 1965-1966. The second period occurred in June - August, 1966.

## EQUIPMENT DESCRIPTION AND OPERATION

The borehole deflectometer is a device which will measure lateral deflections at increments of depth along a prepared borehole, Figure 1. The instrument consists of a guide housing to which a deflection arm is connected by a universal joint. This allows the arm to deflect in relation to the guide housing as the instrument is moved in and out of the cased borehole. Ball bearing rollers 120° apart are mounted on each section. One roller in each set is spring loaded to keep the instrument positioned in the tubing.

A movement of the deflection arm causes a tensioned wire to move with respect to a set of electrical transducers mounted ahead of a knife-edge orifice in the guide housing. It should be noted that the deflection arm may move in any direction. In the model tested, the component of movement is measured in one plane only due to the use of a single set of transducers. The direction of movement is usually noted by (+) and (-). A carrier signal is transmitted to the transducers through the attached cables. This signal is modulated by the movement of the tensioned wire within the field created by the transducers. These signal variations are then returned to the readout unit by the shielded cable.

To take an individual reading, the operator turns a balancing control on the readout unit until an indicator needle is in a null position. The knob for the balancing control has a built-in digital indicator, which is then read. This reading is referenced to a calibration chart to determine deflection in thousandths of an inch.

The instrument is inserted in the borehole using steel rods for orientation. These are indexed by holes drilled through the rods at 30-inch intervals with their axis in the same plane. A set of handles is slipped through the holes and lowered into the slots in the indexing plate. This insures that readings are always taken at the same depth in the hole, and with the same orientation.

The borehole is drilled just large enough to accept the polyethylene or aluminum tube used as a liner. The recommended method of preparing the borehole is to insert the tube, anchor it at the bottom, then grout it in place. A special metal flange is placed at the top of the hole and grouted in at the same time. This flange is drilled and tapped so that the indexing plate may be bolted on when readings are to be made. Between readings a metal cover plate and rubber gasket are bolted on the flange to keep moisture and foreign objects out of the hole.

INSTALLATION ON PROJECT

The actual position of the two 9-inch boreholes drilled by the cement company were on the quarry haul road, below and parallel to the county road in the vicinity of Station 116±. In accordance with the recommendations made by Terrametrics, at that time, these boreholes were lined with a continuous length of 3 in. I.D. polyethylene tubing. However, it was acknowledged that difficulty was to be expected in following this procedure due to the disparity between the size of the tubing and the size of the hole. This tubing is stored in a coil and tends to corkscrew when placed in an oversize hole. Normally, a borehole would be drilled only slightly larger than the outside diameter of the liner. Efforts to straighten the tubing using air pressure and tension were only partially successful.

The grouting operation was conducted with no particular difficulty using neat cement. Smaller holes would have minimized the quantity of grout and the amount of labor required for the installation. As it turned out, the tubing in one of the holes was so crooked after grouting that the instrument could not be inserted. The other hole was approximately 62 ft. deep, and also very crooked. However, it was possible to get the device to the bottom. Actually, a hole with this degree of initial crookedness would not be acceptable for use, as several of the initial readings were at or near the maximum deflection range of the instrument.

Also, this hole was apparently not deep enough to place the bottom of the tube within stable material. This is required in order to provide a reference for the determination of movement. It was decided however that this installation would be satisfactory for the purpose of continuing the evaluation of the deflectometer.

Under the direction of Mr. Horst Ublacker of Terrametrics, the initial readings of the borehole was taken with the deflectometer, and the research personnel received instruction in its use. This was completed in December, 1965.

READING PROCEDURE

Five complete and independent sets of readings were taken over a period from December 17, 1965 to February 8, 1966. Each of the 21 positions down the borehole was read three times by raising and reseating the probe. This was repeated coming out of the hole. The average of the three readings at each position in each direction was then referenced to the calibration charts to determine the deflection. The instrument was checked for zero in the carrying tube before and after each complete set of readings.

At the end of the above period the equipment was returned to Terrametrics. It was then brought back for a month beginning June 13, 1966, and several more sets of readings were taken. This allowed a period of time to elapse, before taking terminal readings, to provide a greater opportunity for the slide to register movement.

DATA ANALYSIS

The most direct and meaningful handling of data appears to be the plotting of individual deflection values versus the depth of borehole. This will show the zones of major movement, if any, and relative movement magnitude. The average standard deviation of individual field measurements of deflections (see Figure 1) over a period of time was estimated to be 0.007 in. This is based on the 5 sets of field readings taken in the December-February period. Inspection of the data suggested that the systematic movement within the period was slight compared to the apparent random scatter of data, and that a correction for trend would not significantly reduce the estimate. It therefore represents the total error over the period of observation which includes: the instrument, the borehole, the calibration, and test procedure. No attempt is made to assign a portion of the error to any particular piece of the equipment or phase of the operation.

It is also technically possible to determine the borehole profile in reference to some initial position. The location of any deflection position with respect to the reference is the double algebraic summation:

$$\sum_{n=1}^{k}\left(\sum_{n=1}^{k} d_{(n)}\right)$$

where d is the individual deflection value, and k is the position number with respect to the reference. It is seen from the nature of this expression that any slight systematic error such as a calibration drift would have an extreme effect on the summation. Because of this fact it would be generally preferable to compare the individual readings, rather than profiles of the borehole.

The cement company's survey data for the period July, 1965, through May, 1966, showed that the slide dropped about three-quarters of an inch at the county road, and moved out about one inch inside the quarry. There was also sloughing of a zone of plastic clayey material inside the quarry, and associated ground water seepage. It is believed that the main zone of movement was below the bottom of the deflectometer borehole. In any event, it was not possible to discern this movement from the deflectometer data.

COMMENTS

Overall, the equipment seemed to be well constructed, and comparatively stable through the period of readings. Some minor trouble was experienced with a cable connector making intermittent contact, which was easily corrected once located. With the present equipment a two-man crew is necessary. About two hours were required for a complete set of readings in the 60-ft. hole. Due to the awkward length of rod sections (about 10 ft.) a pickup truck or similar vehicle is required to transport the equipment. If the device is used in a deeper hole, a hoist is required because of the weight of rod and probe.

If the readings at a point continue to change systematically through several readings, it is necessary to continue reseating the instrument until they become constant or vary about a certain value. It is also important to periodically calibrate the instrument against known deflections. Setting the zero of the instrument in reference to the axis of the carrying case does not provide a check on its reading at a given deflection. As with any measuring device, an external reference is required as a means of gaging the performance of the instrument. It is also noted that if the deflection at a point along the borehole exceeded the range of the deflectometer, it would be necessary to drill and prepare another borehole if further information were desired.

FIGURE I

# INITIAL POSITION OF THE DEFLECTOMETER